NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2906

AN AIRBORNE INDICATOR FOR MEASURING VERTICAL VELOCITY OF AIRPLANES AT WHEEL CONTACT

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SUMMARY

An airborne vertical-velocity indicator has been designed in order to provide a means of obtaining measurements of airplane vertical velocity at the instant of wheel contact.

One such indicator was tested in the Langley impact basin to determine its accuracy and was flight-tested with a small trainer-type airplane to determine its practicability. Vertical velocities ranging from 0.5 to 7.5 fps were obtained in the impact-basin tests. In the flight tests the velocities ranged from 0.5 to 3.2 fps. A second such indicator has been built and flight-tested on a high-speed jet bomber.

The operation of the indicator is described and the data obtained in the investigation are presented. Analysis of the data indicated that this type of vertical-velocity indicator is accurate and practical for obtaining vertical velocities of airplanes at the instant of wheel contact.

INTRODUCTION

Landing-gear loads are governed by several basic parameters such as vertical velocity, airplane weight, and horizontal velocity. Among the more important of these parameters and one which is included in airplane design specifications is the vertical velocity of the airplane during landing. The vertical velocities encountered in actual practice, however, are not accurately known for most types of airplane because of the lack of satisfactory methods for measuring this quantity. The NACA has therefore undertaken a general study of the problem of measuring vertical velocity. The purpose of this paper is to describe one of the means developed for measuring this quantity on a given airplane type - a trailing arm with wheel. This indicator of vertical velocity is attached to the landing gear and contacts the ground just prior to touchdown of the landing-gear wheel. The vertical velocity of the airplane is determined from the angular motion of the trailing arm.

A prototype velocity indicator was tested in the Langley impact basin to determine its accuracy. This indicator was also installed on the landing gear of a small trainer-type airplane and another model, improved in design, was mounted on a high-speed jet bomber to determine their practicability in flight operation. A description of the operation of this type of vertical-velocity indicator, the results of the impact-basin and flight tests, and a general evaluation of the indicator are presented herein.

DESCRIPTION OF THE VELOCITY INDICATOR

The prototype indicator is shown in figure 1; the essential element of this type of velocity indicator is a trailing arm which is secured to the airplane landing gear by an attachment fitting and on which is mounted a small swiveling-wheel assembly. The arm is free to rotate in a plane parallel to the longitudinal axis of symmetry of the airplane. Maximum angular travel of the trailing arm is 45° and is limited at the lower extremity by a stop installed in the attachment fitting and at the upper extremity by full compression of an oleo strut. The oleo strut applies a moment to the trailing arm in such a manner as to cause the trailing wheel to maintain contact with the ground. Side loads on the indicator resulting from taxying and yawed landings are kept to a minimum by the swiveling action of the trailing wheel. The trailing wheel is equipped with a solid rubber tire, size 2×6:00.

The motion of the trailing arm is translated into velocity measurements by means of a small direct-current generator mounted on the lower part of the attachment fitting (fig. 2). The armature of this generator (rotation of $\pm 50^\circ$) is actuated by means of a string which is attached to the generator shaft at one end and passes over a cam that is rigidly attached to the trailing arm. The output of the generator depends upon the rotational velocity of its armature and is unaffected by temperature and accelerations.

The design of the cam was governed by two considerations; first, sufficient periphery was provided to utilize the full linear range of the generator through the maximum angular travel of the trailing arm. Second, the peripheral shape of the cam was chosen so that the output of the generator was proportional to the component of trailing-wheel velocity parallel to the landing-gear strut axis. The relationships of the velocity vectors when the trailing wheel contacts the ground and when the airplane wheel contacts the ground are shown in figure 3. From this figure it is seen that the trailing-arm angle changes considerably from the time of trailing-wheel contact to airplane-wheel contact. Consequently, the velocity of the trailing wheel normal to the arm varies considerably from the vertical velocity; however, during this time the component of trailing-arm velocity parallel to the landing-gear strut varies much less from the vertical velocity. In order to obtain an output from the generator proportional to the velocity parallel to the landing-gear strut, the cam radii were made directly proportional to $\sin(\phi + \theta)$, which is the angle between the trailing-arm axis and the center line of the landing gear.

The following equations were obtained from the relationships shown in figure 3:

$$V_n = \frac{V_v}{\sin \theta} \tag{1}$$

and

$$V_p = V_n \sin(\phi + \theta) \tag{2}$$

where the symbols are defined as follows:

V_n trailing-wheel velocity relative to the airplane and in a direction normal to the trailing arm

V_v component of V_n normal to the ground (vertical velocity of airplane at landing contact)

V_p component of V_n parallel to main landing-gear strut

ϕ angle between center line of landing-gear strut and vertical

θ angle between trailing-arm axis and vertical

CALIBRATION AND INSTRUMENTATION

The equipment setup for calibrating the generator consisted of a one-horsepower electric motor, a variable-speed drive, and a small flywheel connected to the trailing arm by an adjustable link (fig. 4). Calibrations were made at two positions of the trailing arm by changing the length of the connecting link and repositioning the equipment so that the setup shown in figure 5 was maintained. These calibrations served as a check on the phase relationship between the cam and the trailing arm and also on the calculated shape of the cam. A calibration curve including the individual test points obtained with the connecting link set at 30 and 37 inches is shown in figure 6. This curve indicates that, regardless of the positions of the trailing arm, the same calibration curve was obtained. A linear control-position transmitter was attached to the oleo strut (fig. 2) and was calibrated in terms of trailing-arm angle. From this calibration the values of θ and ϕ at wheel contact were determined.

A strain-gage-type accelerometer was mounted on the lower mass of each landing gear to indicate the instant of contact of each of the airplane main wheels (fig. 1).

The output signals of the generator, slide wire, and accelerometers were recorded on a four-channel oscillograph. The galvanometer elements were all electromagnetically damped at approximately 65 percent of critical and had a flat response range from 0 to 5 cycles per second. These low-frequency galvanometers were used in order to reduce the extraneous high-frequency vibrations picked up by the trailing arm.

APPARATUS AND TEST PROCEDURE

Impact-Basin Tests

In order to determine the accuracy of the vertical-velocity indicator, the prototype indicator shown in figure 1 was tested in the Langley impact basin. (See fig. 7.) The impact-basin equipment (ref. 1) provides means for dropping the test specimen at a constant vertical velocity while the carriage is stationary or moving horizontally. A description of this equipment and its adaptation to the testing of landing gears is given in reference 2. In order to use this equipment for testing landing gears with forward speed, a concrete runway was installed in the impact basin. This runway was placed at the normal water level and is removable. The installation of the velocity indicator in the impact-basin tests is shown in figure 7.

The vertical and horizontal velocities of the landing gear in the impact-basin tests were obtained by the carriage instruments described in reference 1. The instant of airplane-wheel contact was obtained by means of a switch on the carriage dropping mechanism which was closed automatically at contact.

The tests in the impact basin consisted of 24 runs. The landing gear was inclined 10° and 20° to the vertical, these being the approximate angles obtained with the airplane in the level and three-point attitudes. Five tests with a forward speed of approximately 85 fps were made at each landing-gear inclination. Seven tests without forward speed were made at each gear inclination. The vertical velocity of the landing gear at main-wheel contact was measured over a range of 0.5 to 7.5 fps. The landing-gear inclination remained fixed throughout the run.

Flight Tests

The flight tests of the prototype indicator were made with a two-place single-engine trainer-type airplane having a gross weight of 5200 pounds. The landing gear is of the single-leg half-forked type and is equipped with a 27-inch-diameter tire. The velocity indicator was secured to the stationary upper portion of the left landing-gear strut.

Fourteen landings were made, eleven on the concrete runways at Langley Field, Virginia, and three on concrete runways at a nearby airport. The vertical velocities ranged from 0.5 to 3.2 fps at the time of contact of the left main wheel. The landing-gear inclination ranged from approximately 9° to 19°. The range of horizontal landing speed was between 95 and 125 fps.

In this initial installation not much regard was given to size and weight of the attachment fitting nor were provisions made for retraction of the landing gear since the primary purpose of the investigation was to determine the accuracy and practicability of the indicator. Improvements were therefore incorporated in a later model to make the unit more compact and to provide for use with a retractable landing gear. Figure 8 shows this model installed on the high-speed jet bomber. It was found that the small commercially obtained wheel used on the trailing arm in the initial flight tests would not stand up under the repeated high-speed landings of the bomber. A special wheel was therefore developed for this installation and a number of landings have been made, but not enough data have been obtained to warrant an analysis in this paper.

RESULTS AND DISCUSSION

Typical oscillograph records obtained during the impact-basin and flight tests of the prototype of the vertical-velocity indicator are shown in figures 9 and 10, respectively. Sample records obtained with the improved design on the jet bomber are presented in figure 11. The vertical velocity associated with the landing gear at the instant of airplane-wheel contact was derived by substitution of the experimentally obtained values in the following equation which is obtained from equations (1) and (2):

$$V_v = V_p \frac{\sin \theta}{\sin (\phi + \theta)}$$

The results of the impact-basin tests are presented in figure 12, in which the vertical velocities obtained from the airborne vertical-velocity indicator are compared with those obtained from the carriage vertical-velocity instrument. The agreement shown indicates that the velocity indicator is capable of measuring the vertical velocity of an airplane at the instant of wheel contact with reasonable accuracy. The indicator was installed on the trainer-type airplane to determine whether a readable record could be obtained during actual landings and the effect of the indicator on the airplane handling qualities. The oscillograph records (figs. 9, 10, and 11) were of very good quality and were easily evaluated to determine vertical velocity. The pilots of the airplane observed that the indicator had no noticeable effect on the take-off, landing, or ground handling characteristics of the airplane.

The experience gained in testing the prototype instrument pointed out some improvements which it would be desirable to incorporate into the design. Effort has therefore been made to locate the trailing wheel directly below the axle of the main wheel and this position was provided in the case of the bomber installation. This location results in a condition wherein the indication of the instant of airplane-wheel contact is a function only of angular position of the trailing arm and, for all practical purposes, is independent of the inclination of the landing-gear strut. The instant of wheel contact can then be determined by means of a properly located switch installed on the linkage of the indicator. Furthermore, this location of the trailing wheel yields the true vertical velocity of the landing gear, unaffected by any pitching velocity of the airplane.

CONCLUDING REMARKS

An airborne indicator for measuring the vertical velocity of an airplane at wheel contact has been built and successfully tested. The prototype of this indicator was tested in the Langley impact basin, where comparison with the standard instrumentation used there to measure vertical velocity established the accuracy of measurement with the indicator. This same indicator was tested in flight on a small trainer-type airplane to establish its practicability. The prototype proved practical for flight use, so that a second model which is more compact and is suitable for use on a retractable landing gear was built and successfully used on a high-speed jet bomber.

The wheel on the trailing arm used in the impact-basin tests and on the trainer airplane touched the ground at a point some distance behind the landing gear to which the arm was attached. This point of ground contact of the trailing-arm wheel was relocated at a more favorable longitudinal position on a transverse line through the contact point of the landing gear in the bomber installation.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 5, 1952

REFERENCES

1. Batterson, Sidney A.: The NACA Impact Basin and Water Landing Tests of a Float Model at Various Velocities and Weights. NACA Rep. 795, 1944. (Supersedes NACA ACR L4H15.)

2. Milwitzky, Benjamin, and Lindquist, Dean C.: Evaluation of the Reduced-Mass Method of Representing Wing-Lift Effects in Free-Fall Drop Tests of Landing Gears. NACA TN 2400, 1951.

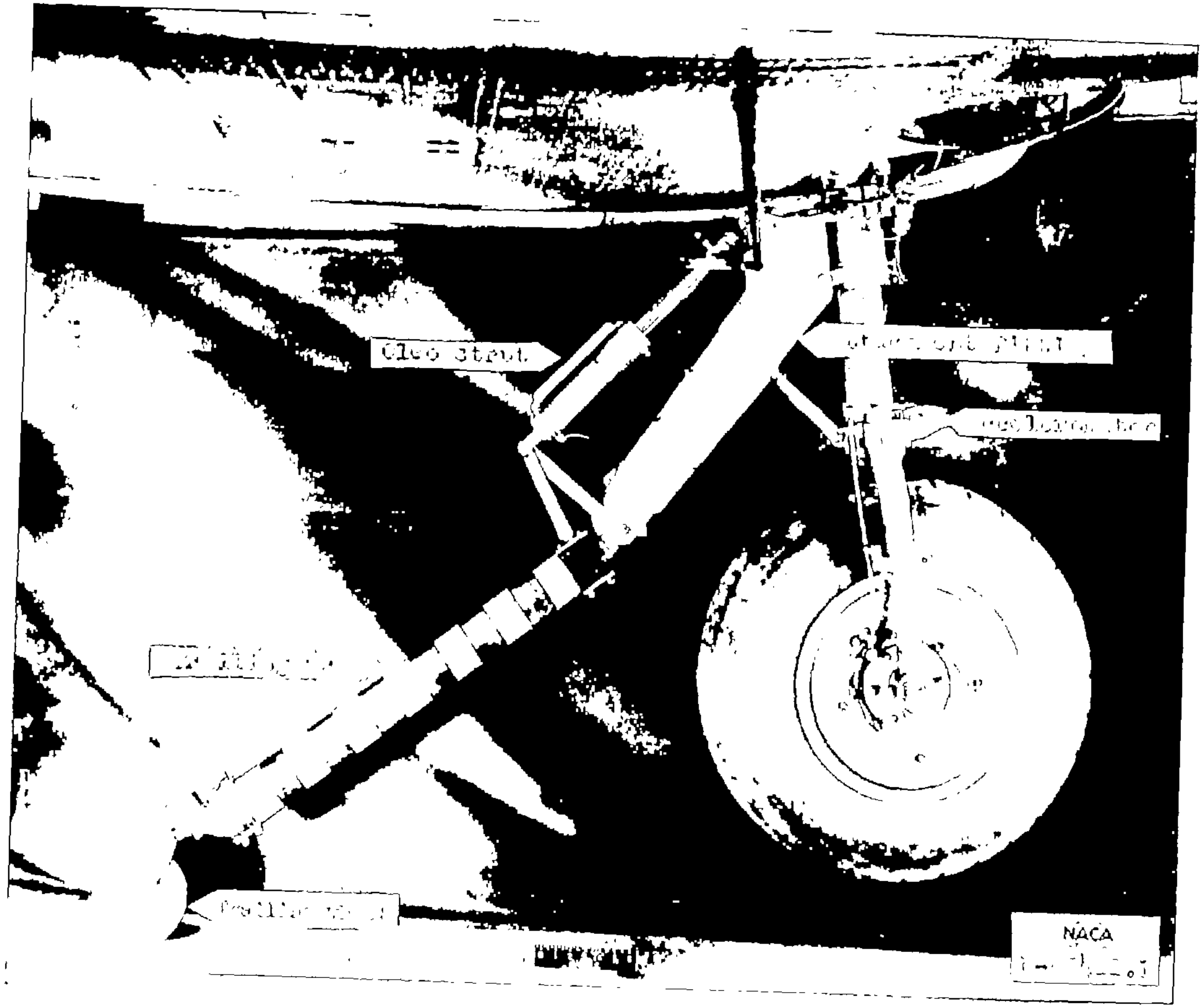


Figure 1.- Components of vertical-velocity indicator.

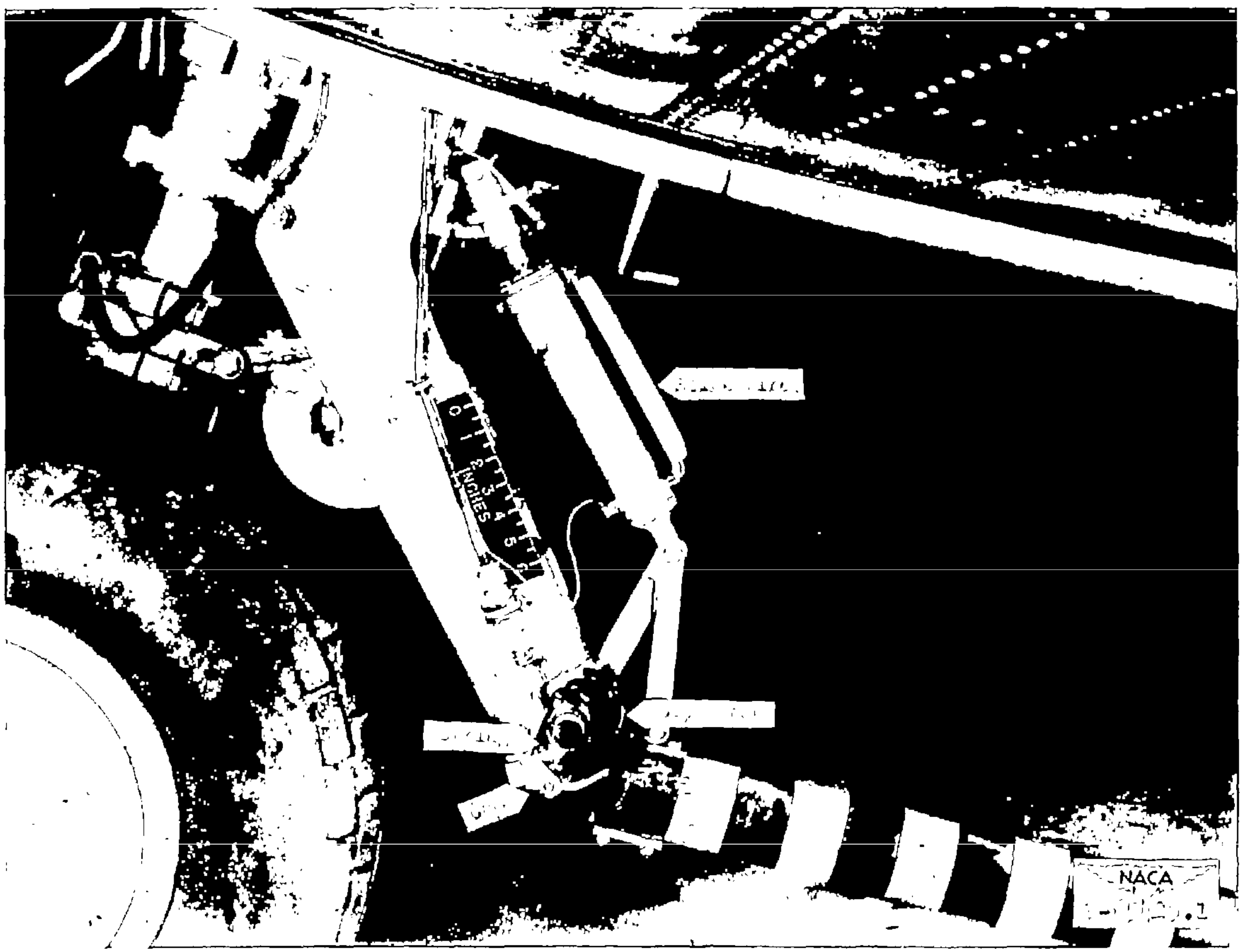


Figure 2.- Detail of vertical-velocity indicator.

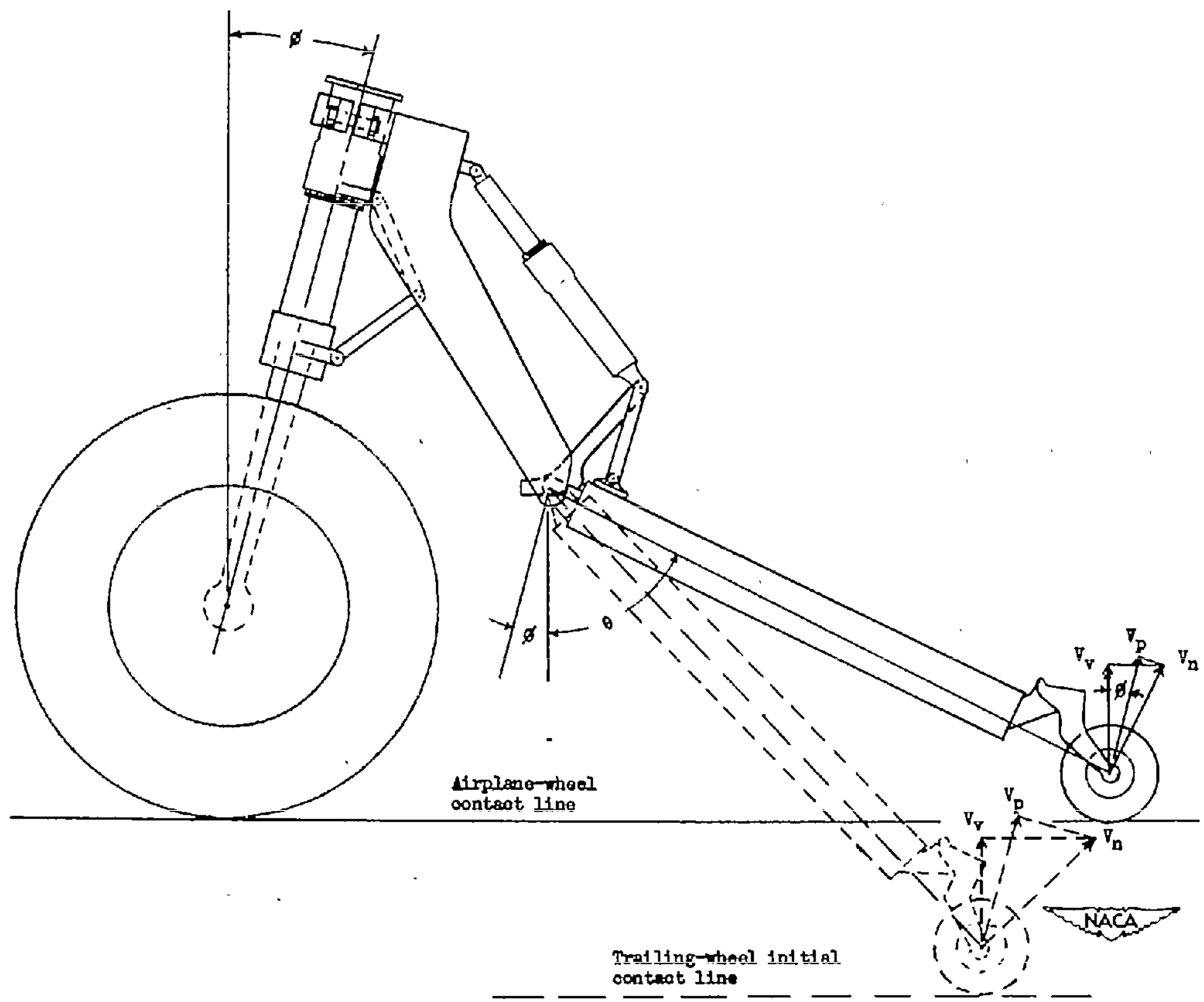


Figure 3.- Velocity vectors and angles of velocity indicator at two positions of trailing arm.

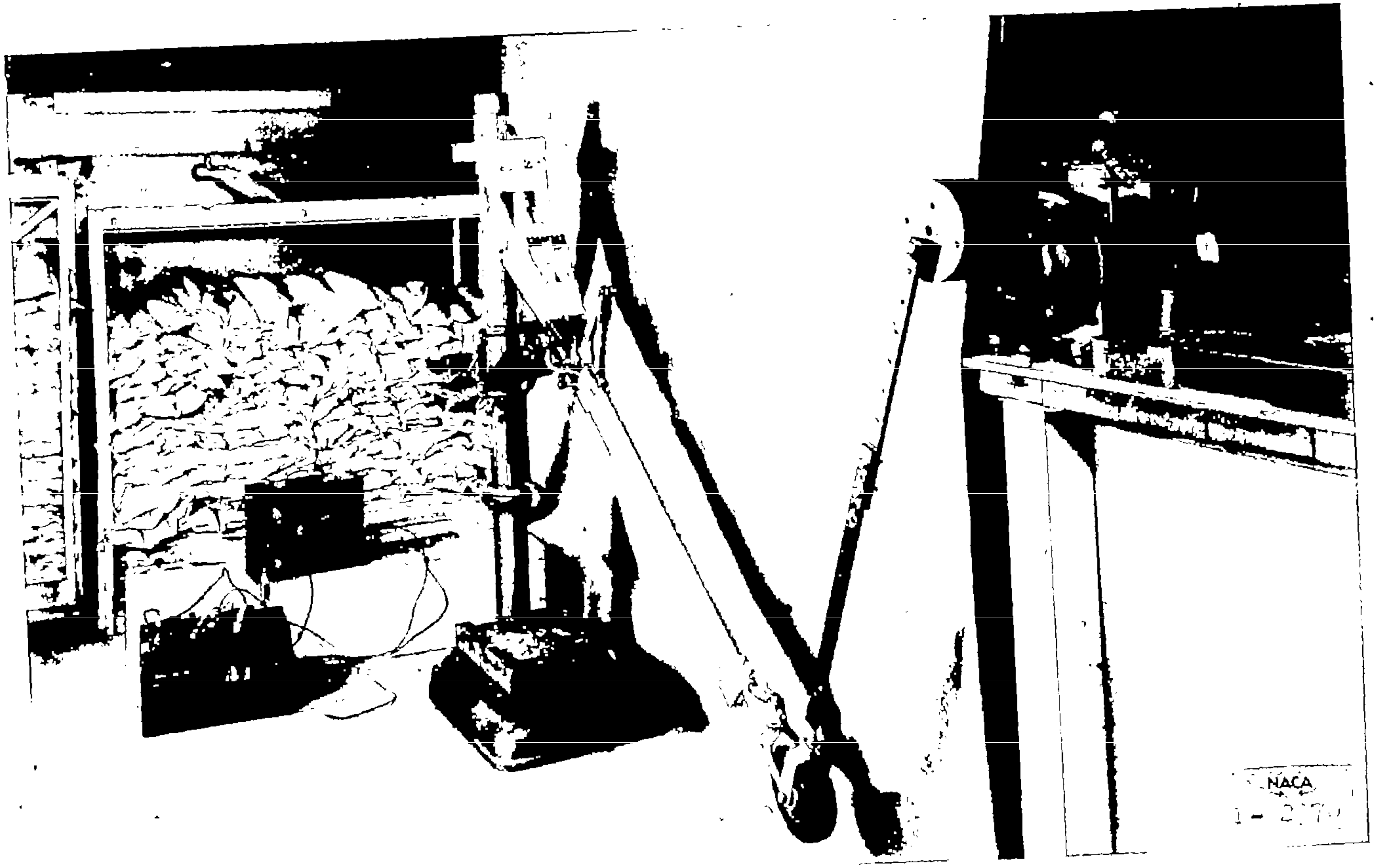


Figure 4.- Setup for calibration of generator.

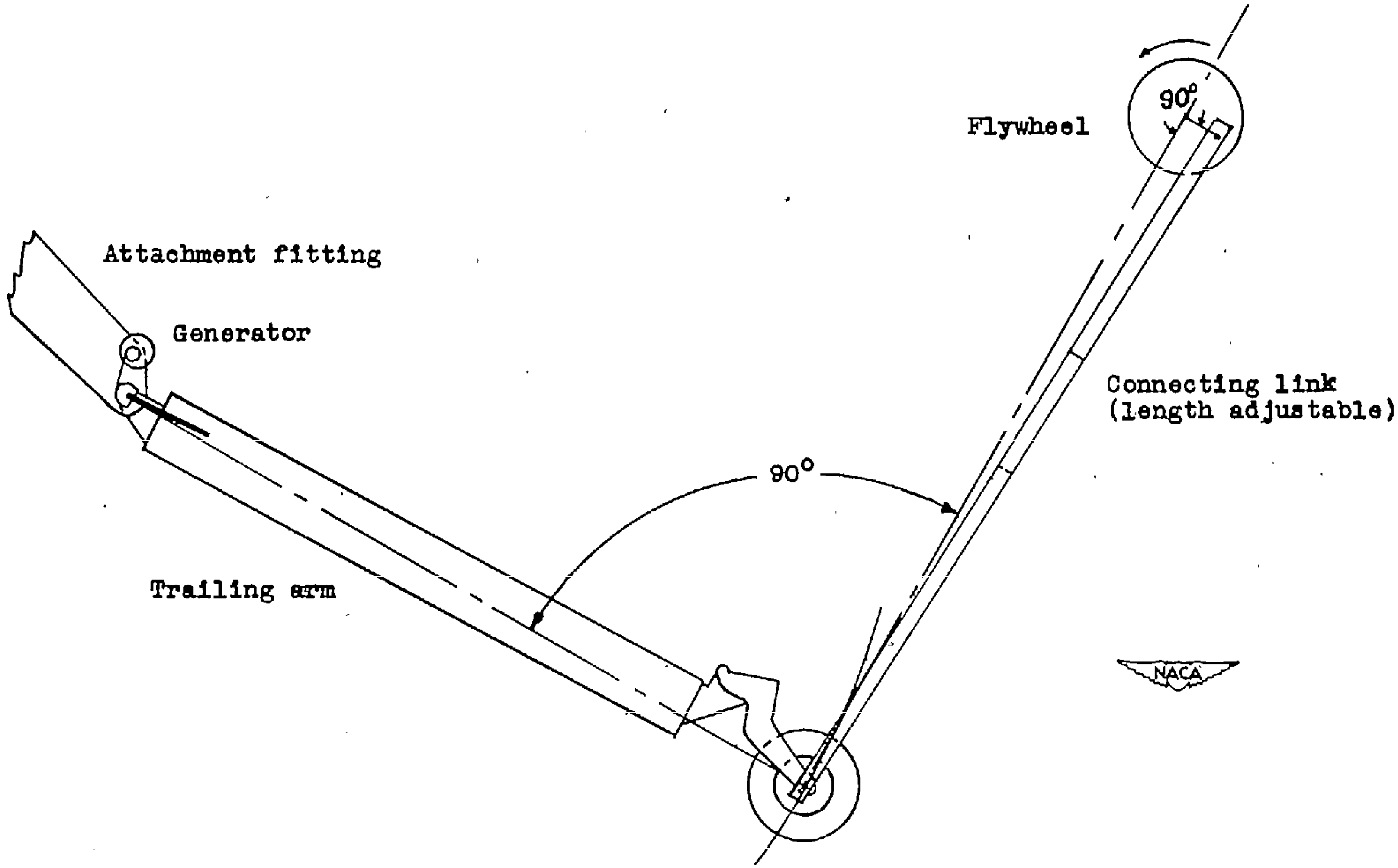


Figure 5.- Schematic drawing of calibration setup.

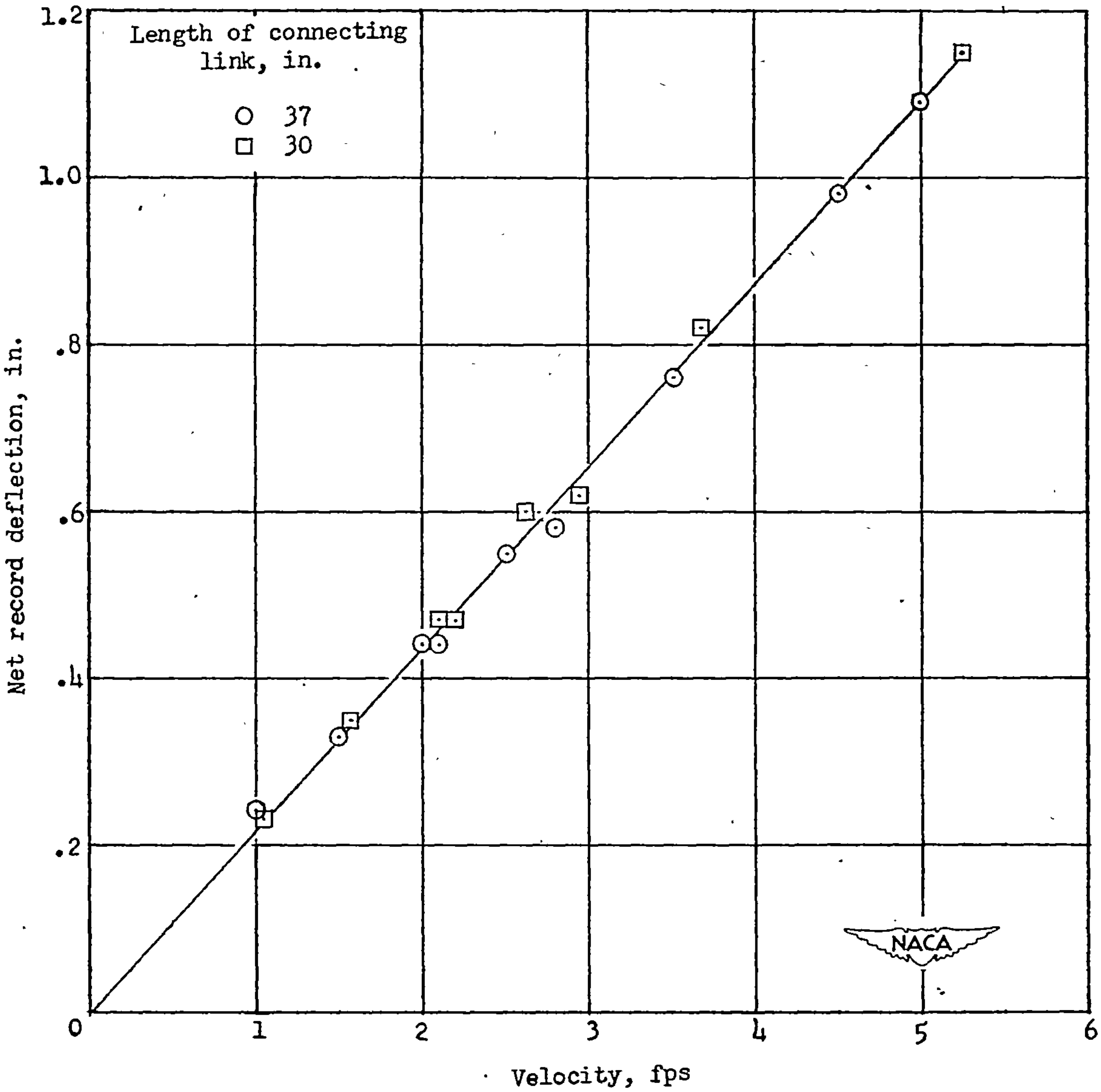


Figure 6.- Velocity-indicator calibration curve.

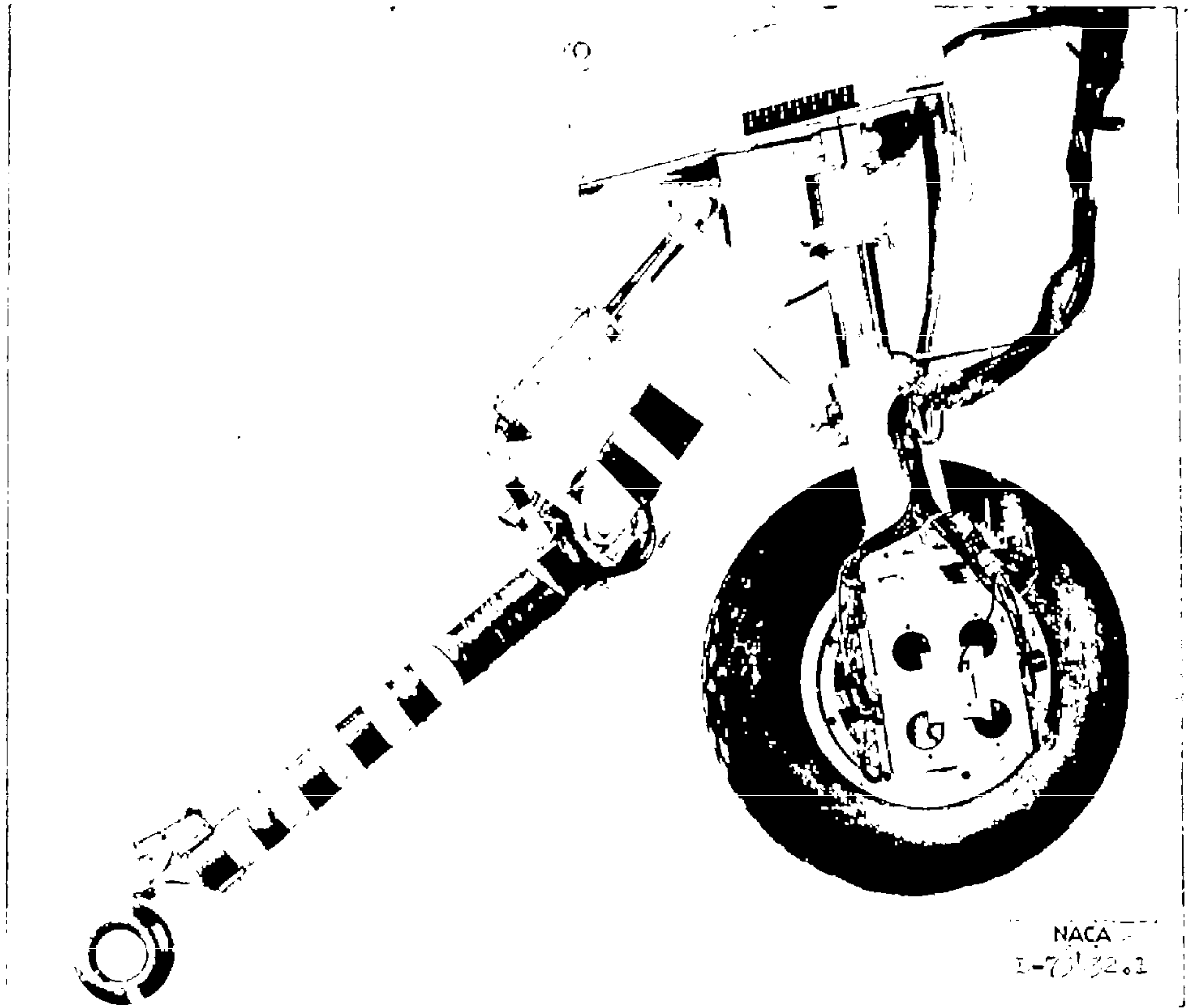


Figure 7.- View of velocity-indicator installation on landing gear used in Langley impact-basin tests.

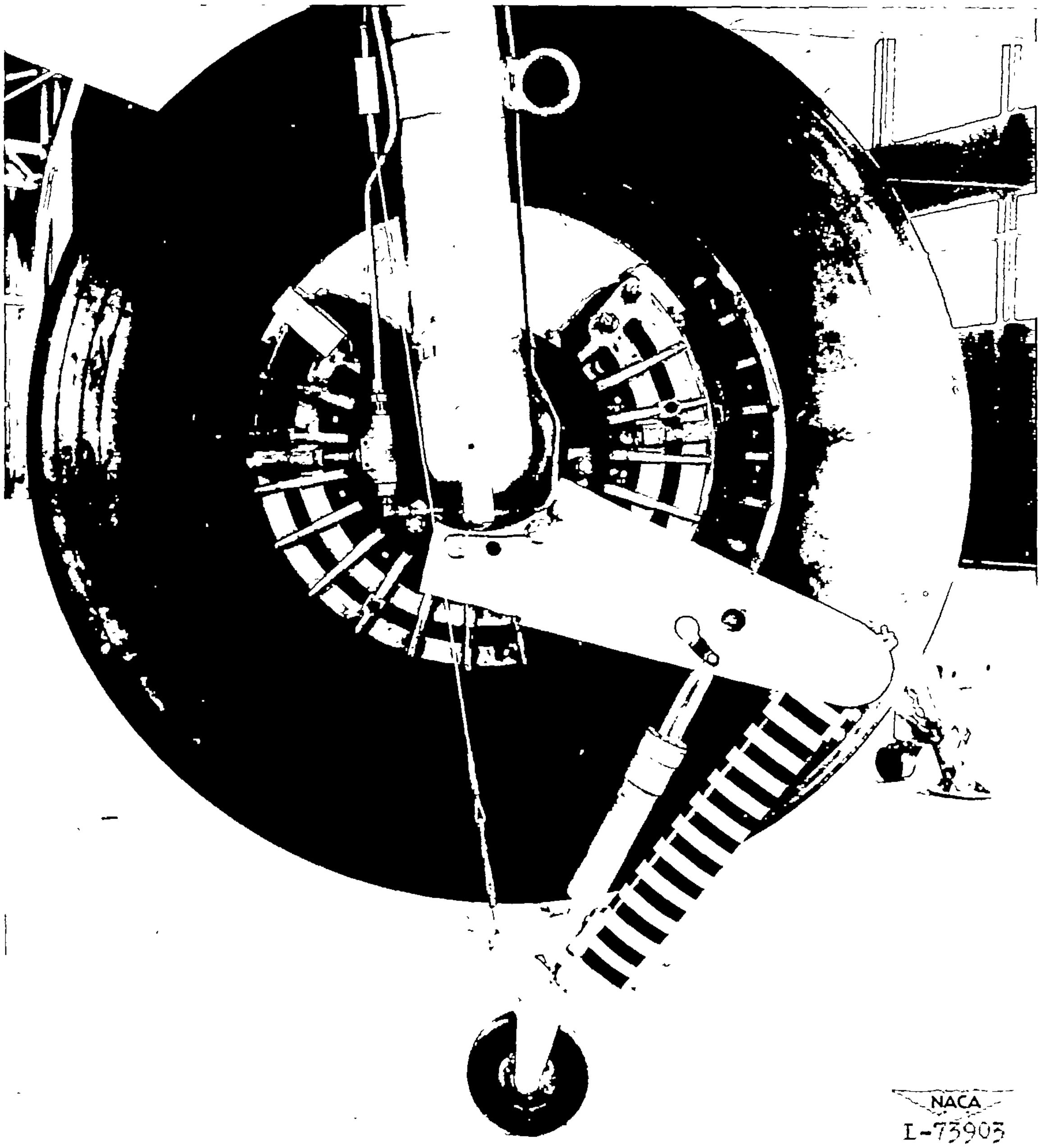
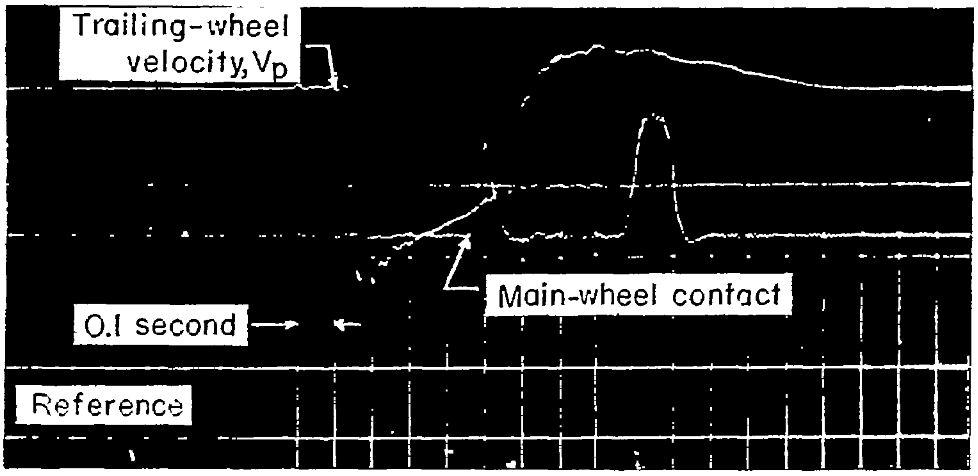
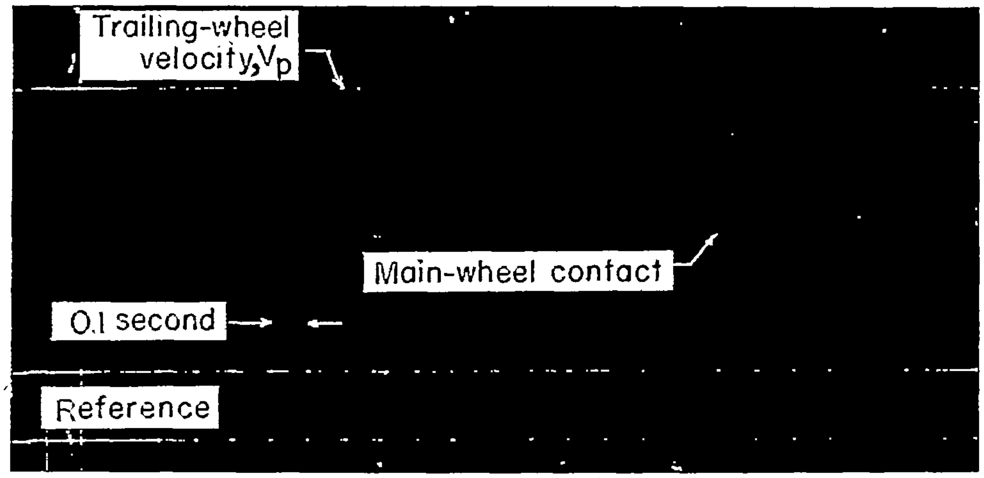


Figure 8.- Retractable vertical-velocity-indicator installation on bomber-type airplane.

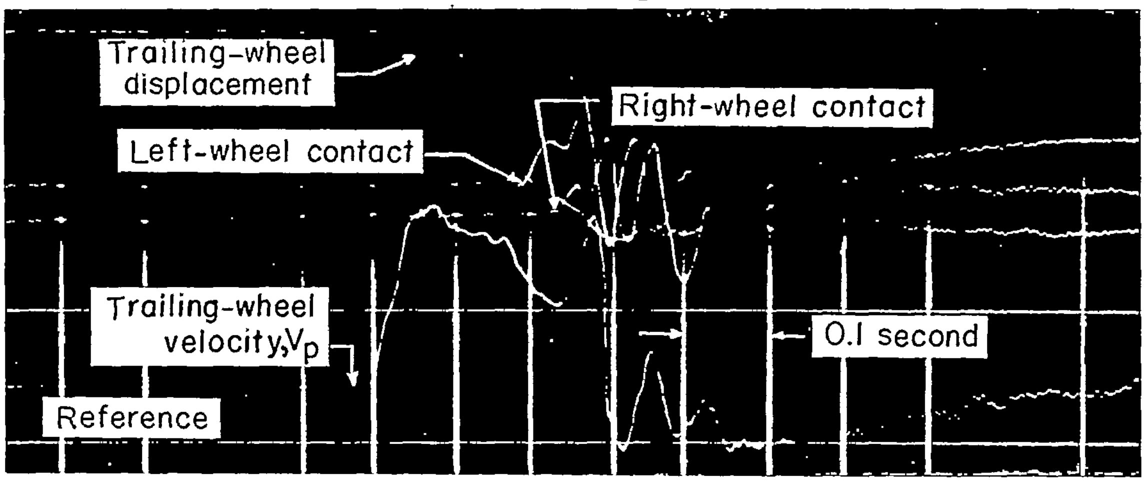


(a) Vertical velocity at main-wheel contact, 3.2 fps.

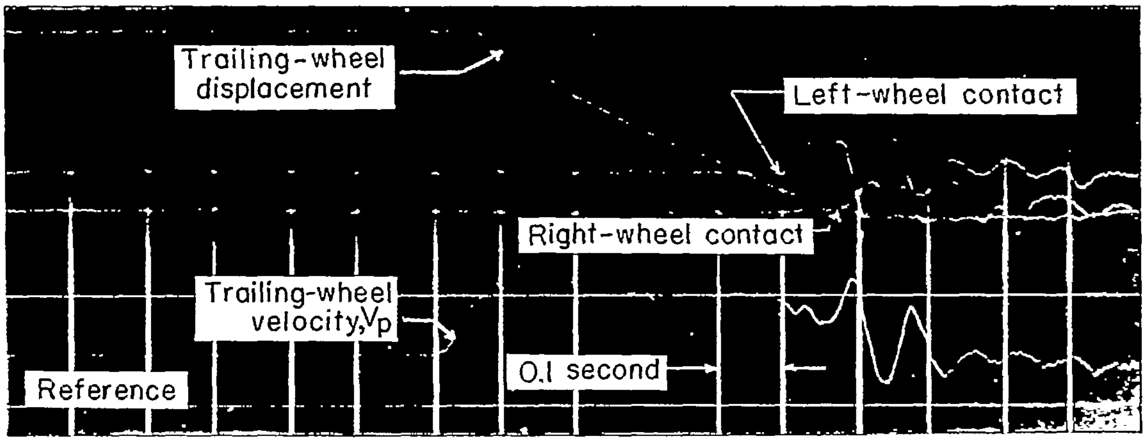


(b) Vertical velocity at main-wheel contact, 0.4 fps.

Figure 9.- Typical oscillograph records obtained in impact-basin tests.

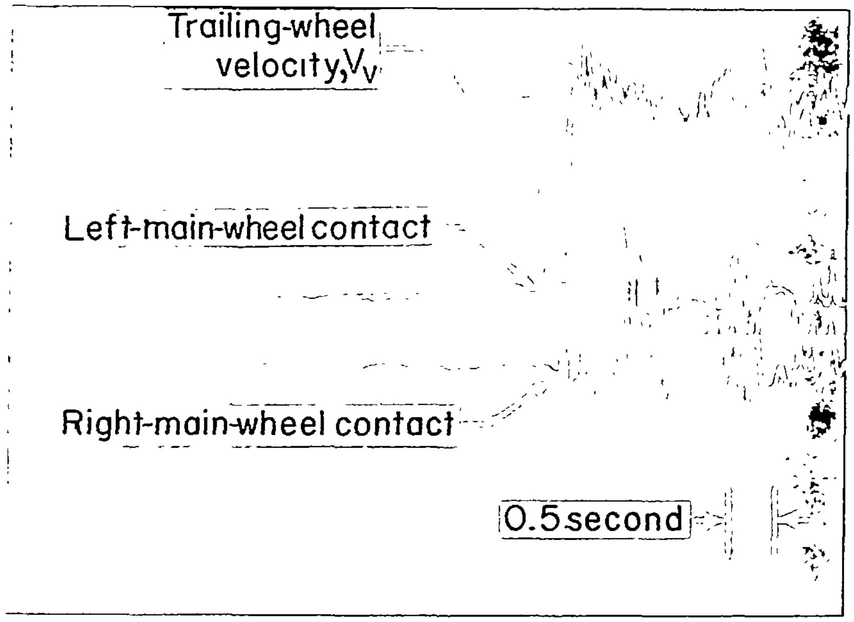


(a) Vertical velocity at left-wheel contact, 2.5 fps.

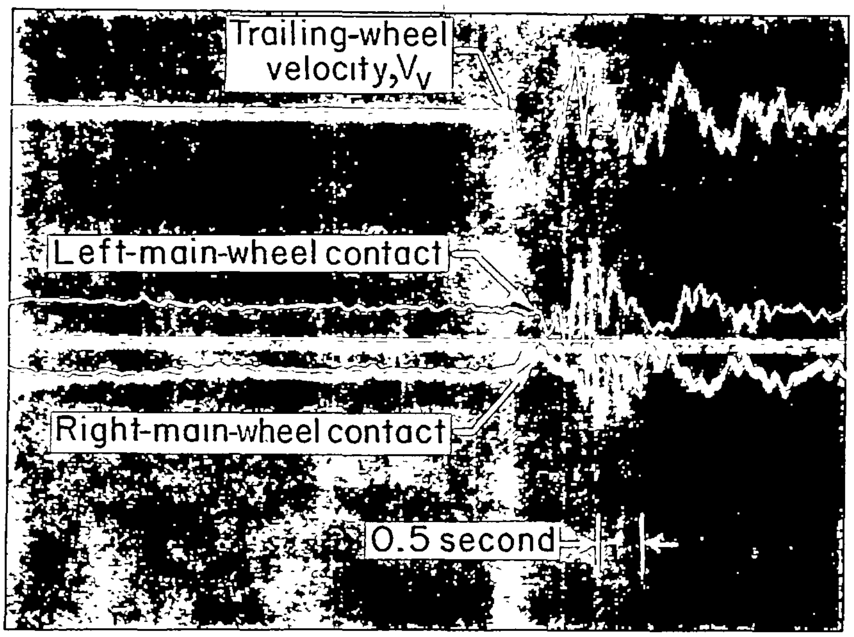


(b) Vertical velocity at left-wheel contact, 1.2 fps.

Figure 10.- Typical oscillograph records obtained in flight tests.



(a) Vertical velocity at left-main-wheel contact, 3.6 fps.



(b) Vertical velocity at left-main-wheel contact, 1.2 fps.

Figure 11.- Typical oscillograph records obtained with improved velocity indicator on high-speed airplane.

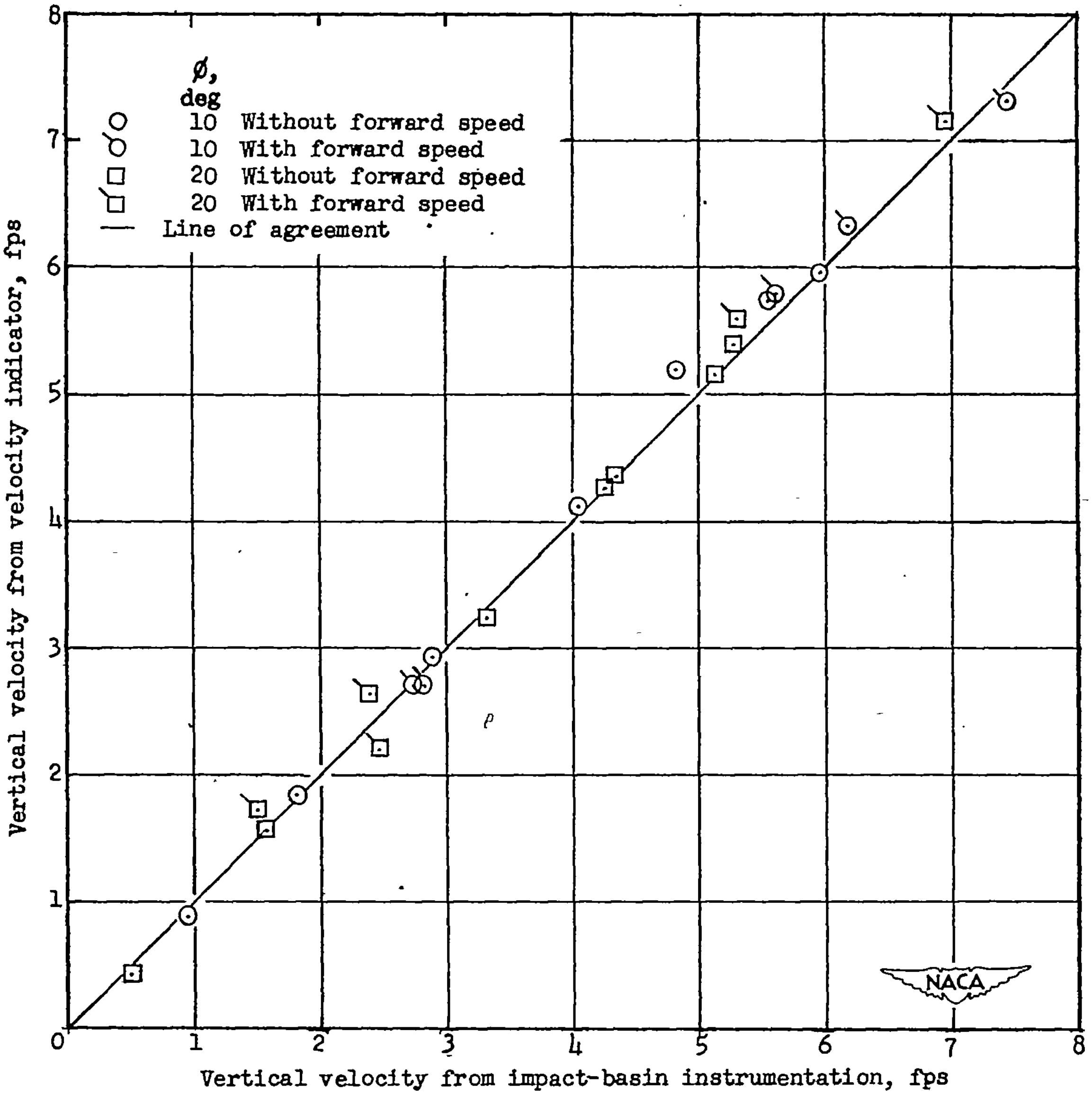


Figure 12.- Comparison of vertical velocity obtained from velocity indicator with vertical velocity obtained from impact-basin-carriage instrumentation.

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